

From Programmatic Goals to Chlorophyll *a* Criteria

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Interstate Commission on the Potomac River Basin

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James River Chla Criteria Study
Scientific Advisory Panel



“Logic Train”

From Programmatic Goals to Criteria for Phytoplankton Chlorophyll a

White paper dated August 16, 2015 (circulated to SAP on September 16, 2015)

- I. Programmatic goals
- II. Numeric thresholds for water quality
- III. Biotic integrity of phytoplankton
- IV. “Balanced, indigenous, desirable” aquatic life
- V. Chl a as indicator of phytoplankton biotic integrity
- VI. Deleterious effects of algal blooms
- VII. Protectiveness of Chl a criteria
- VIII. Choice of Chl a criteria statistic

I. Programmatic Goals

Narrative programmatic goals express society's wishes for a restored Chesapeake Bay

Goals relevant to phytoplankton are found in CBP agreements, Congress' Chesapeake Bay Restoration Act of 2000, EPA Office of Inspector General report

- Nutrient concentrations that limit formation of algal blooms

- Water clarity adequate for normal photosynthesis by "aquatic plants"

Virginia Water Quality Standards

- Control of "substances nourishing undesirable or nuisance plant life"
(9 VAC 25-260-20)

II. Reference WQ Conditions

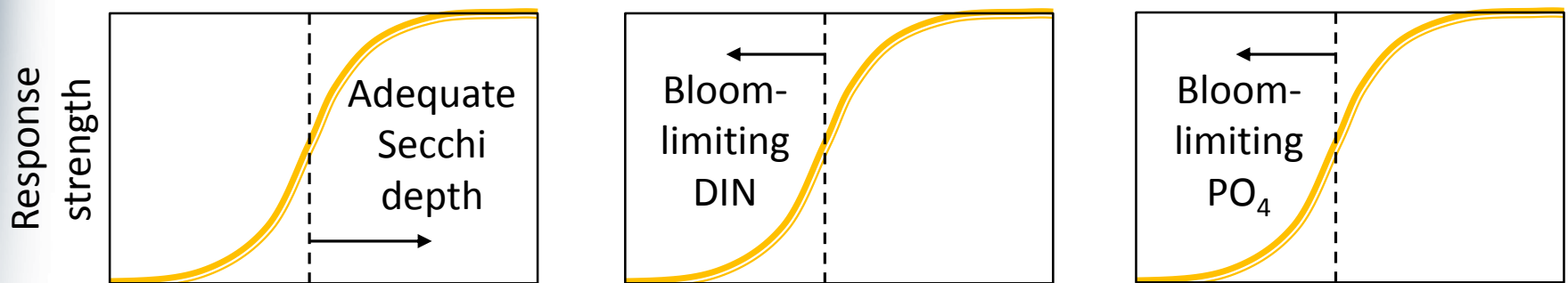
Reference water quality conditions are narrative water quality goals quantified

Numeric thresholds for Secchi, DIN, PO_4 have been identified for phytoplankton

Algal bioassays experiments (Fisher & Gustafson, Haas, others)

Analysis of Chesapeake monitoring data (Alden, Perry, Olson, others)

Literature



II. Reference WQ Conditions (cont.)

Combinations of DIN + PO₄ + Secchi characterize four distinctly different phytoplankton habitat categories (“bins”)

REF, MBL, MPL, DEG (Nov 2013 presentation)

Bins are commonly used in research and management to classify habitats, analyze communities & run models scenarios

Reflects Liebig’s “Law of the Minimum”
Allows adaptive, nuanced management



Reference conditions are attainable in Chesapeake Bay

III. Biotic Integrity

Reference conditions are home to biological communities with “good” integrity

Reference populations can be used as benchmarks or standards against which other populations are measured

Karr 1981; Gibson *et al.* 2000; Martinez-Crego *et al.* 2010; others

Reference-based multi-metric indices represent biological integrity better than single parameters

National Academy of Science & others, for an array of ecosystems

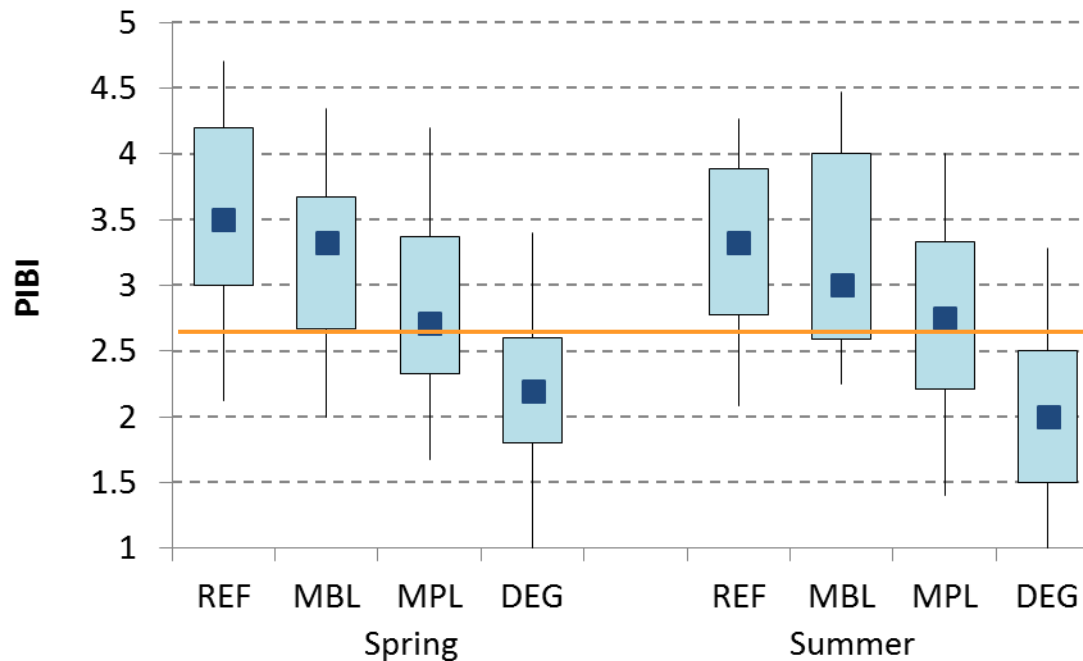
[IBIs are] “the most powerful tool existing to identify systemic impacts on the health of biological systems.” (Wikipedia!)

III. Biotic Integrity (cont.)

Phytoplankton Index of Biotic Integrity (PIBI)

Good classification efficiency overall (~77% bay-wide)

Clear differences between REF & DEG communities (5 – 9 biometrics)



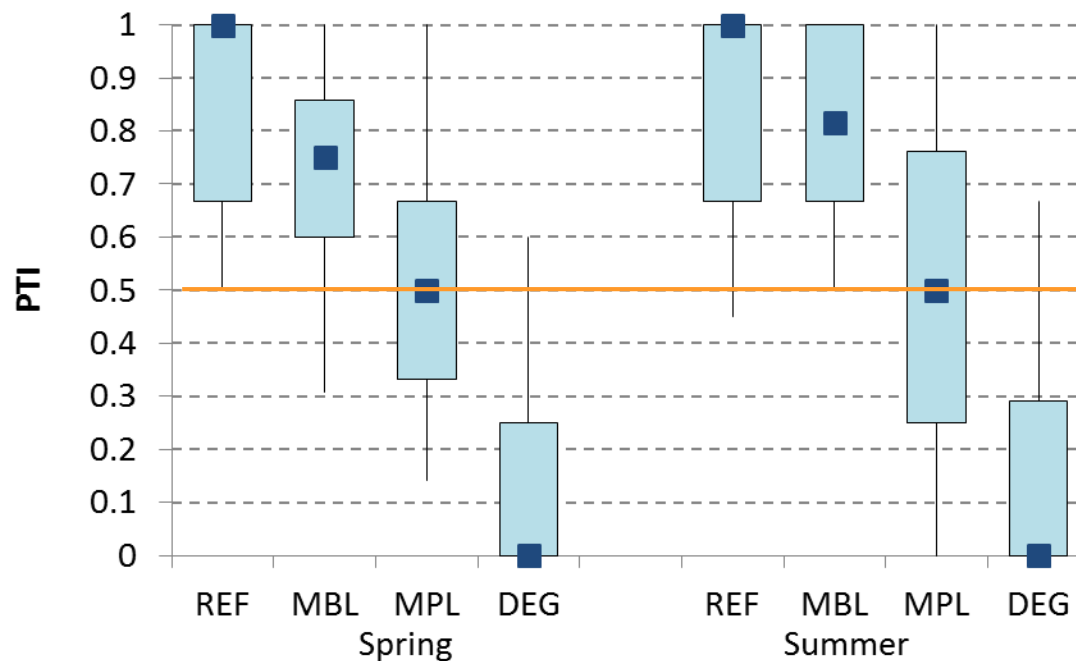
e.g., high salinity waters (>10 ‰)

III. Biotic Integrity (Cont.)

Phytoplankton Taxonomic Index (PTI)

Better classification efficiency (89% spring; 90% summer)

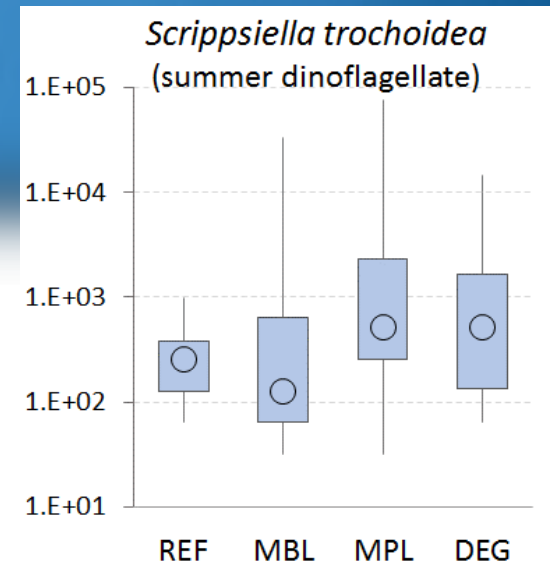
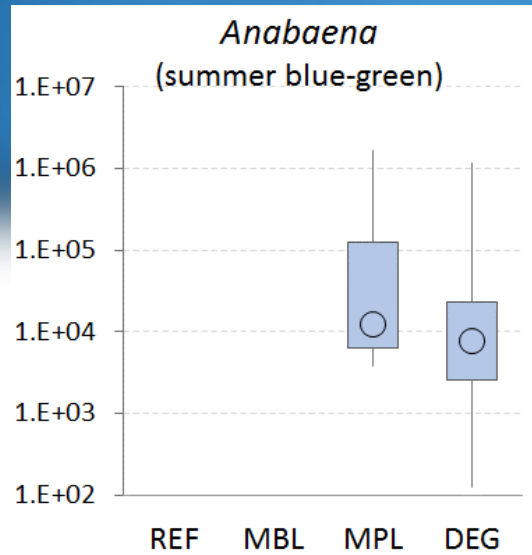
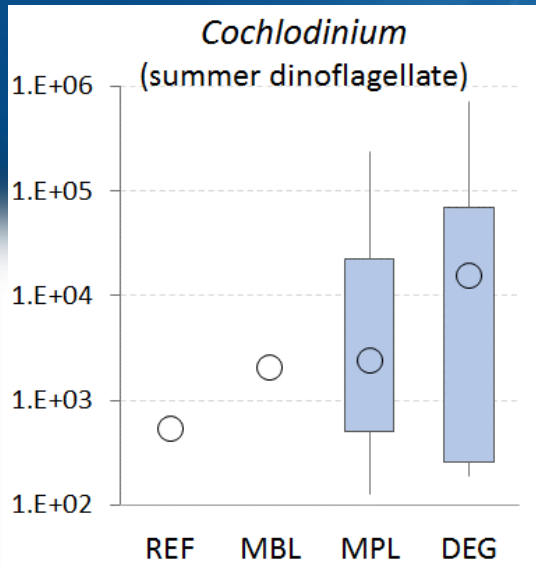
Clear differences between REF & DEG communities (abundances of 77 taxa)



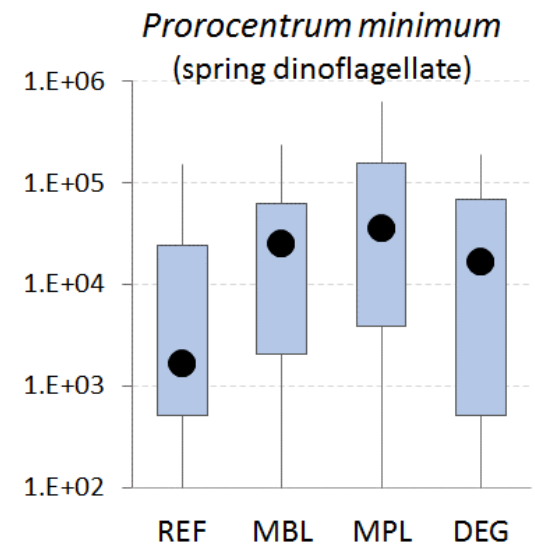
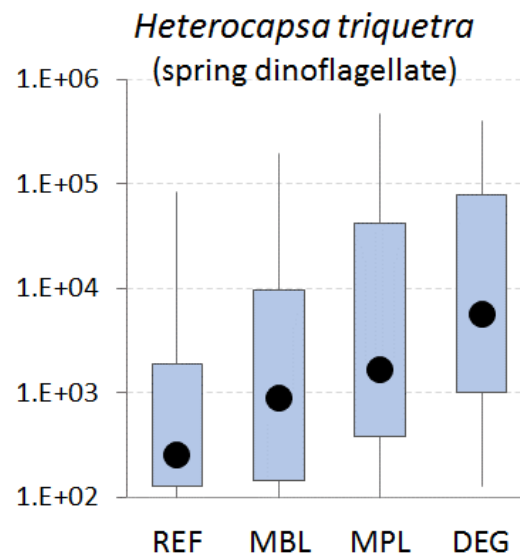
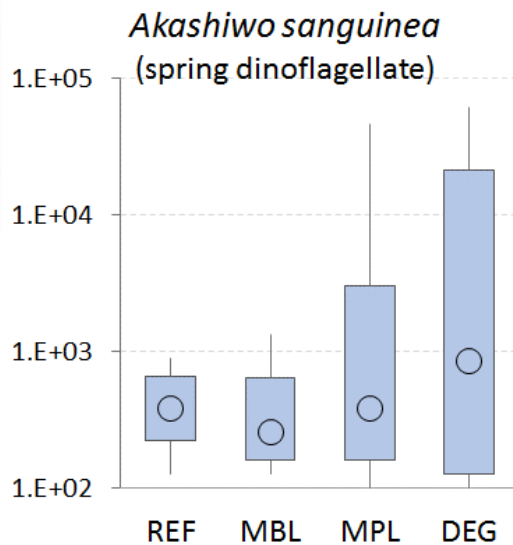
e.g., high salinity waters (>10 ‰)

III. Biotic Integrity (Cont.)

Toxin-Producer



Nuisance



IV. Balanced, Desirable Aquatic Life

Designated Use: “The propagation and growth of a **balanced, indigenous population of aquatic life**, including game fish, which might reasonably be expected to inhabit [Virginia waters]” (9 VAC 25-260-10)

- 1) One intention of the standards is to *protect* the aquatic life designated use in all Virginia waters
- 2) The designated use concerns *biological populations*, not individual parameters such as Chla

IV. Balanced, Desirable Aquatic Life (cont.)

Phytoplankton populations living in desirable Chesapeake water quality conditions (Reference) are desirable aquatic life

- Stable levels of total biomass with low risk of algal blooms/busts

- Adequate food levels for grazers

- Comparatively high taxa richness

- Small percentages of blue-greens and dinoflagellates

- Rare occurrence/low abundance nuisance or toxic taxa

- Unstressed photosynthesis (Chla:C ratio)

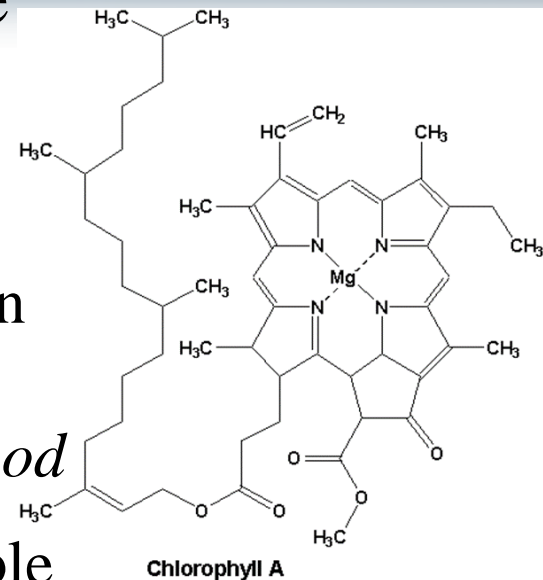
- Unstressed physiology (DOC, pheophytin)

- Relatively large average cell size

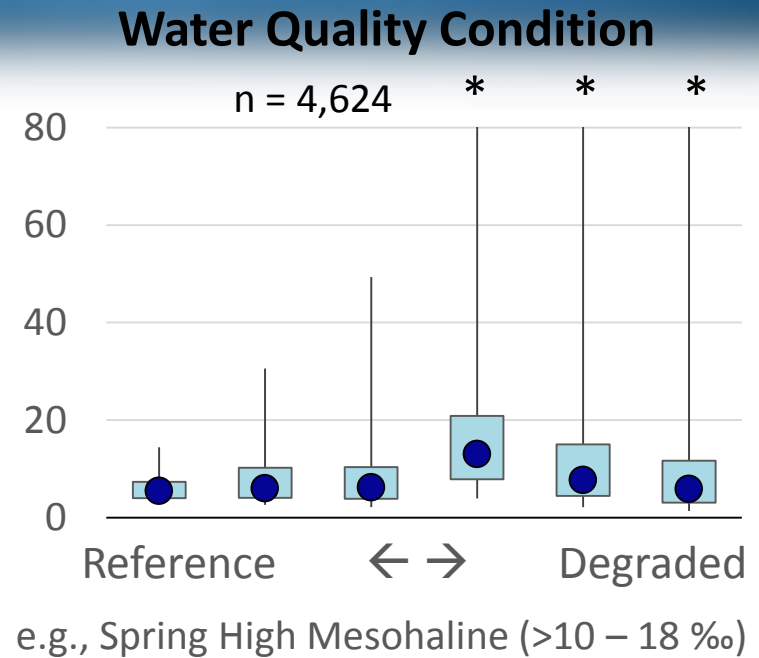
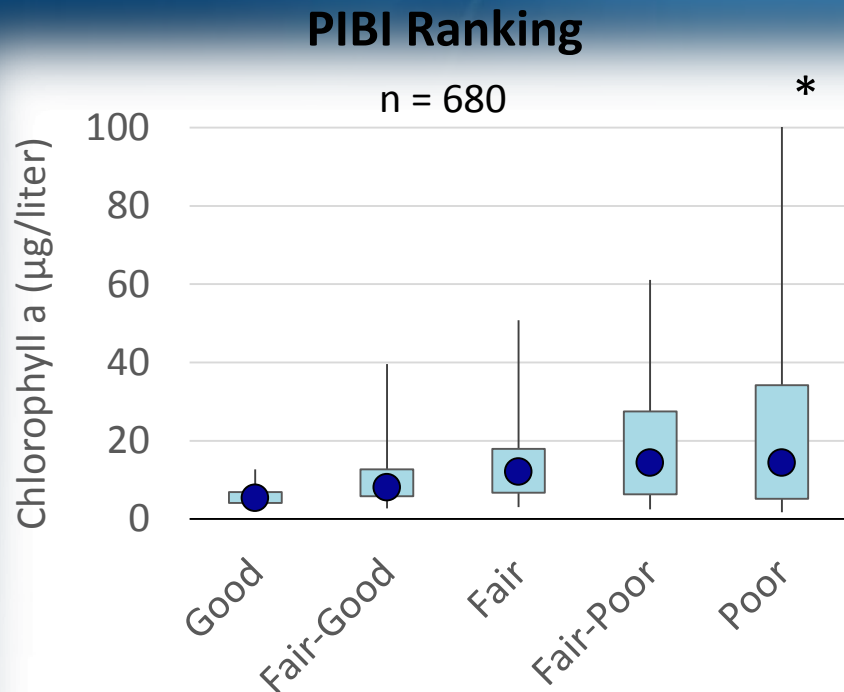
V. Chla as Indicator of Biotic Integrity

Chlorophyll *a* is a light-sensitive molecule necessary for photosynthesis

- Is not an indicator of water quality, *per se*
- Is one of several indicators of phytoplankton responses to water *clarity* and an indirect measure of biomass *when conditions are good*
- Individual Chla values are not always reliable indicators of phytoplankton responses to water quality
- ...but the statistical properties of large Chla data sets do indicate phytoplankton biotic integrity



V. Chla as Indicator of Biotic Integrity (cont.)



Low Chla levels are found in all phytoplankton rankings and water quality conditions, but support different communities

Frequent occurrences of high Chla levels correspond *only* to Fair-Poor or Poor PIBI status and Degraded water quality conditions

(see also Extra Slides 1 & 2)

V. Chla as Indicator of Biotic Integrity (cont.)

Chla in Reference phytoplankton communities achieve Virginia's narrative Chla criteria

“Concentrations of Chla in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences – such as reduce water clarity, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic life or humans or aesthetically objectionable conditions – or otherwise render tidal waters unsuitable for designated uses”

Note that narrative criteria calls for *protection against* deleterious effects of algal blooms and *protection of* designated uses

VI. Deleterious Effects of Algal Blooms

Blooms (high-Chla events) are recognized as having immediate and long-term negative impacts (EPA 2003 and 2007b, numerous studies)

Excess dead algae from blooms is consumed by bacteria - leads to summer **hypoxic/anoxic layers** in deeper waters

Single species blooms represent **poor food quality** - can produce **toxins** that impair grazers

Large blooms can **reduce light** penetration, or water column clarity, at critical times for SAV



Non-algal materials **reduce light** and stress algal photosynthesis much more often than planktonic algal blooms block light to SAV

VII. Protectiveness of Chla Criteria

Two aspects to protectiveness:

Protection of balanced, indigenous, desirable aquatic life

Protection against deleterious effects of blooms

To investigate protectiveness...

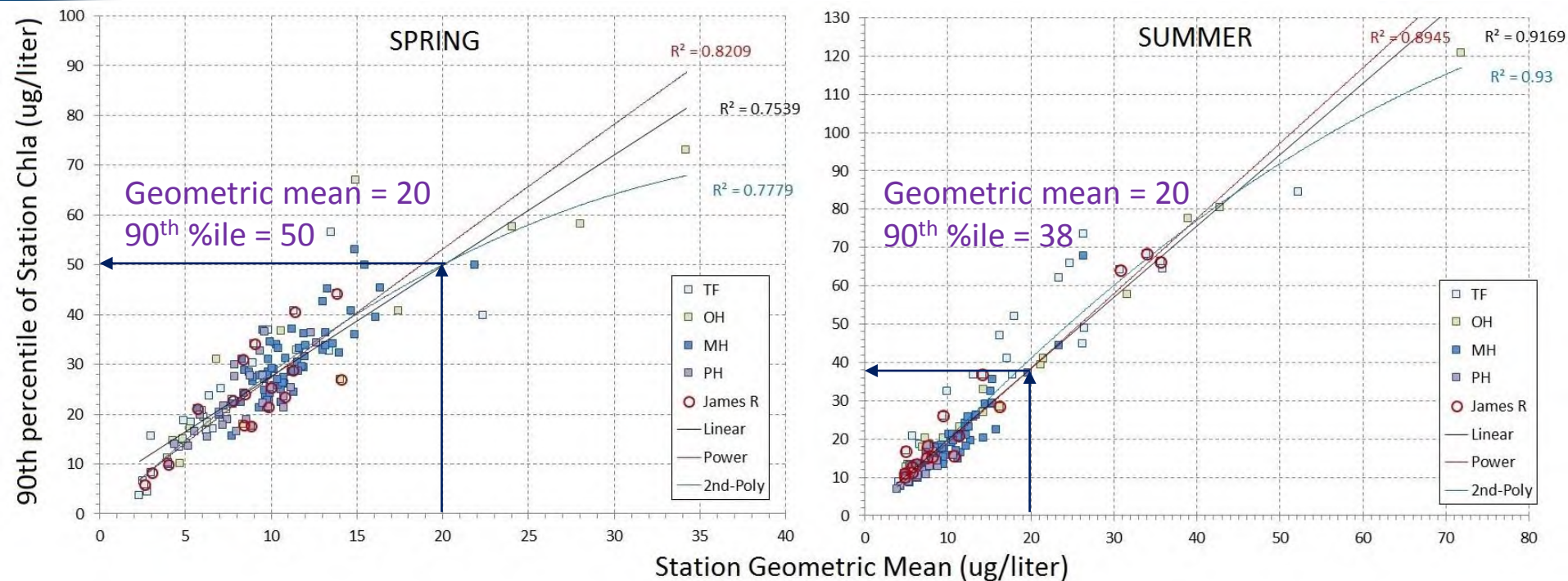
1) Relationship between the mean and its upper limit

For example:

- Determine the expected upper limit of the Chla distribution when seasonal JR criteria are expressed as geometric means
- Then compare those upper limits to Reference community upper limits

VII. Protectiveness of Chla Criteria (cont.)

Station means vs station upper limit (90th percentile)



Data: 137 fixed stations in tidal waters bay-wide; $n \geq 50$ per station; all available data (1984-2013)

NOTE: James River (o) is not so different

See also Extra Slide 3

VII. Protectiveness of Chla Criteria (cont.)

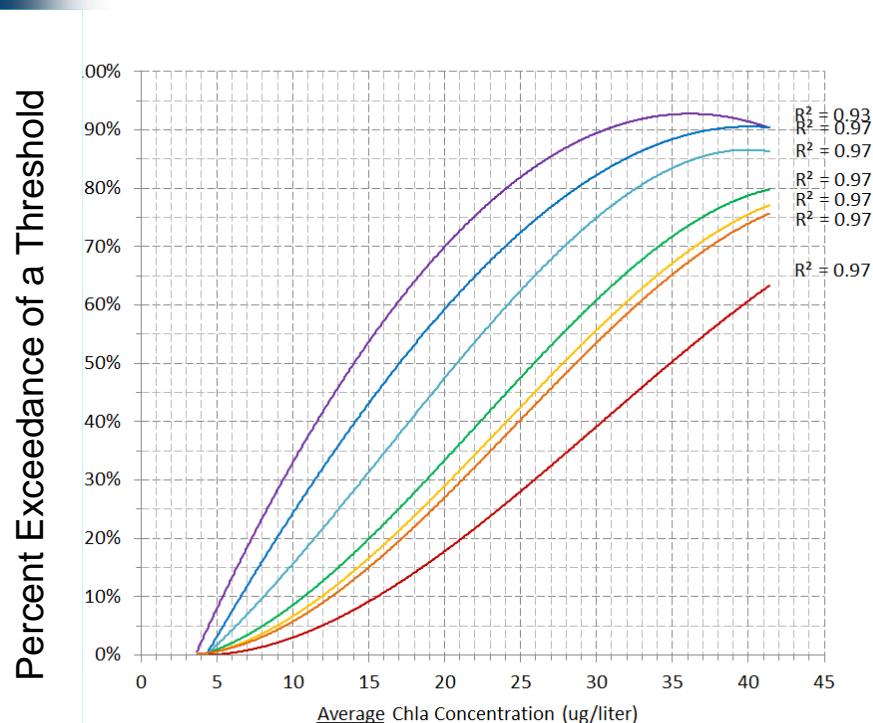
2) Relationship between the mean and % exceedance of a known upper limit or threshold

For example:

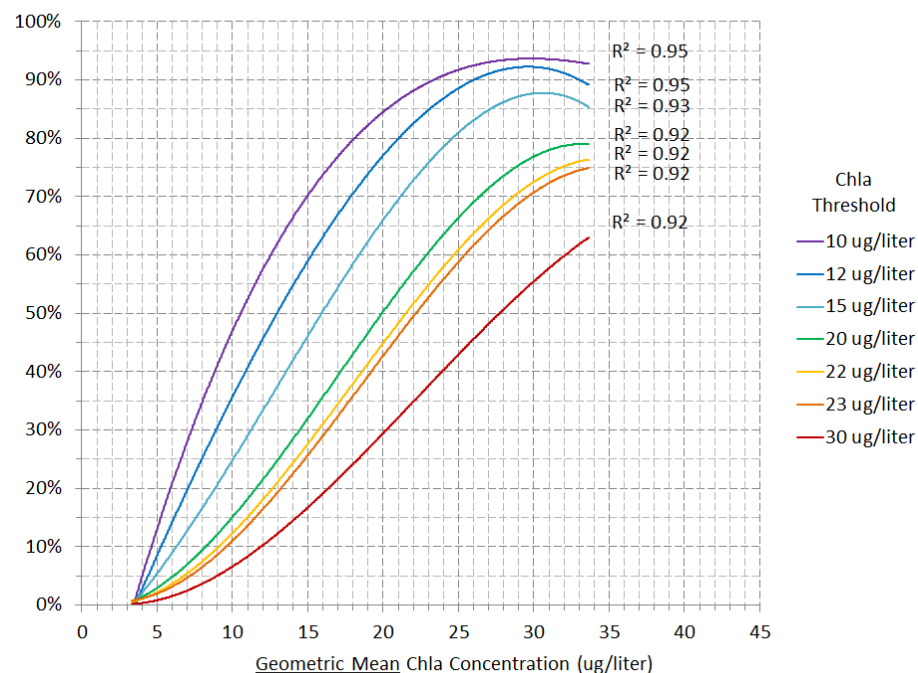
- Pick a threshold to test (e.g., Reference 90th %ile)
- Determine % of samples that can be expected to exceed that threshold for a given Chla seasonal mean (e.g., James R Chla criteria)

VII. Protectiveness of Chla Criteria (cont.)

Mean vs % exceedance of a threshold

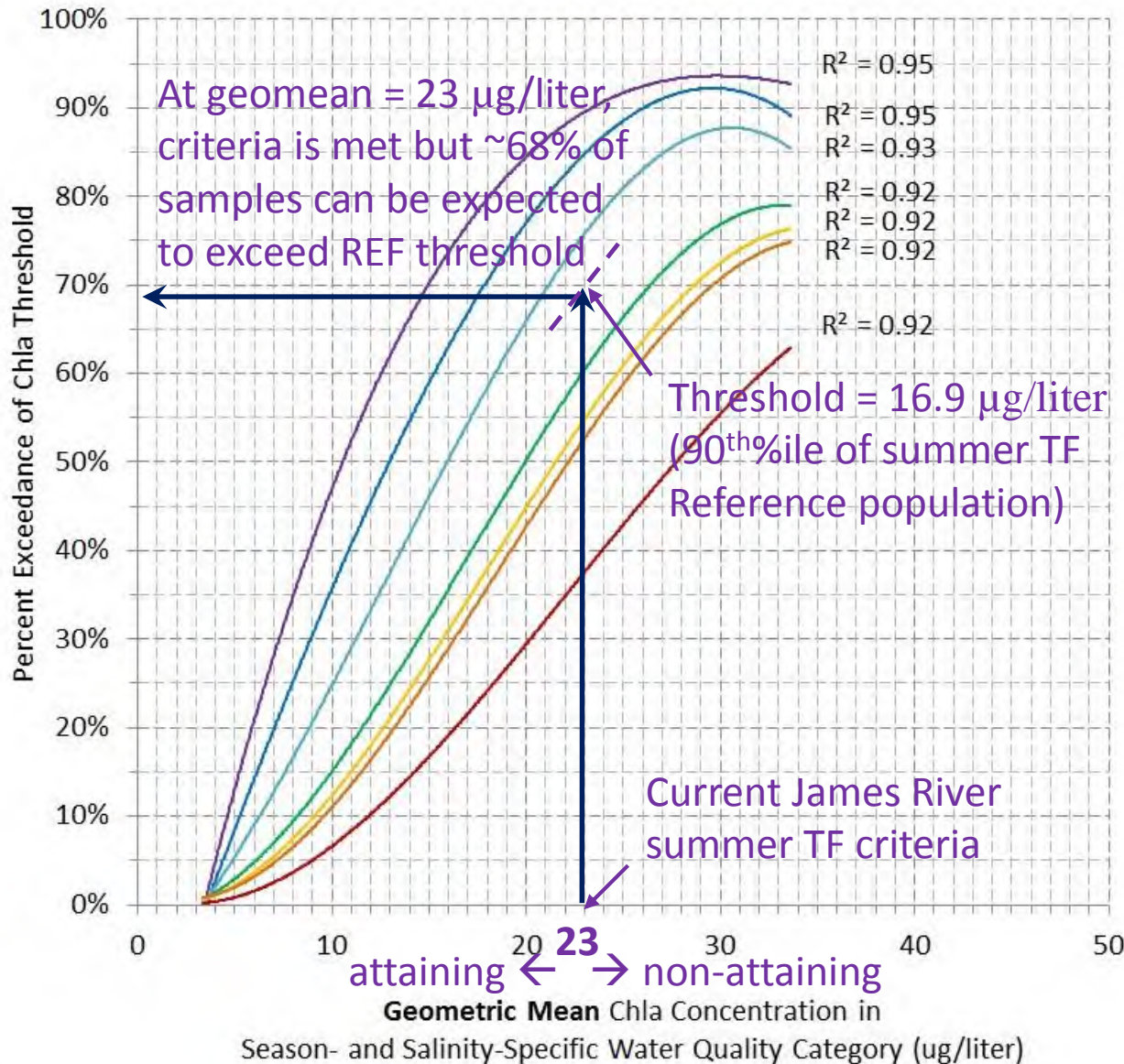


Arithmetic Mean



Geometric Mean

VII. Protectiveness of Chla Criteria (cont.)

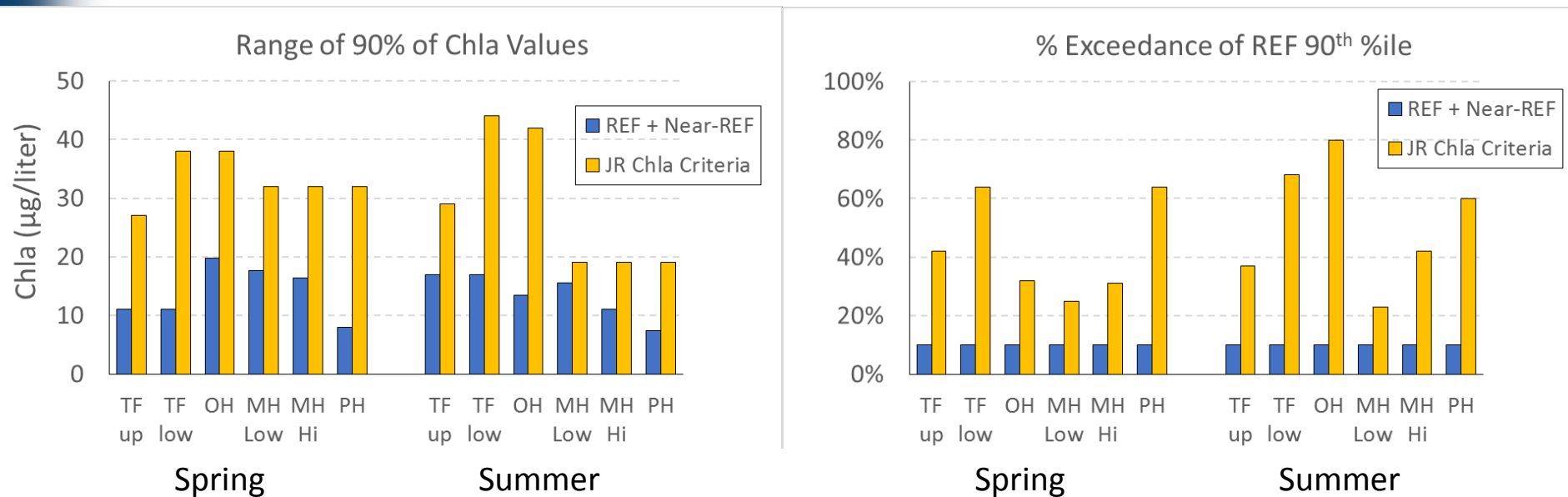


Chla Threshold
10 $\mu\text{g/liter}$
12 $\mu\text{g/liter}$
15 $\mu\text{g/liter}$
20 $\mu\text{g/liter}$
22 $\mu\text{g/liter}$
23 $\mu\text{g/liter}$
30 $\mu\text{g/liter}$

Curves derived from fixed station data bay-wide

VII. Protectiveness of Chla Criteria (cont.)

The current criteria do not protect Reference phytoplankton



VII. Protectiveness of Chla Criteria (cont.)

The current criteria also do not protect

Reference SAV habitats (nearshore waters have $< 15 \mu\text{g Chla/liter}$)

Batiuk *et al.* 2000 Technical Synthesis – habitat requirements

Reference benthic habitats ($< 21 \mu\text{g Chla/liter}$ to protect 30-day DO crit.)

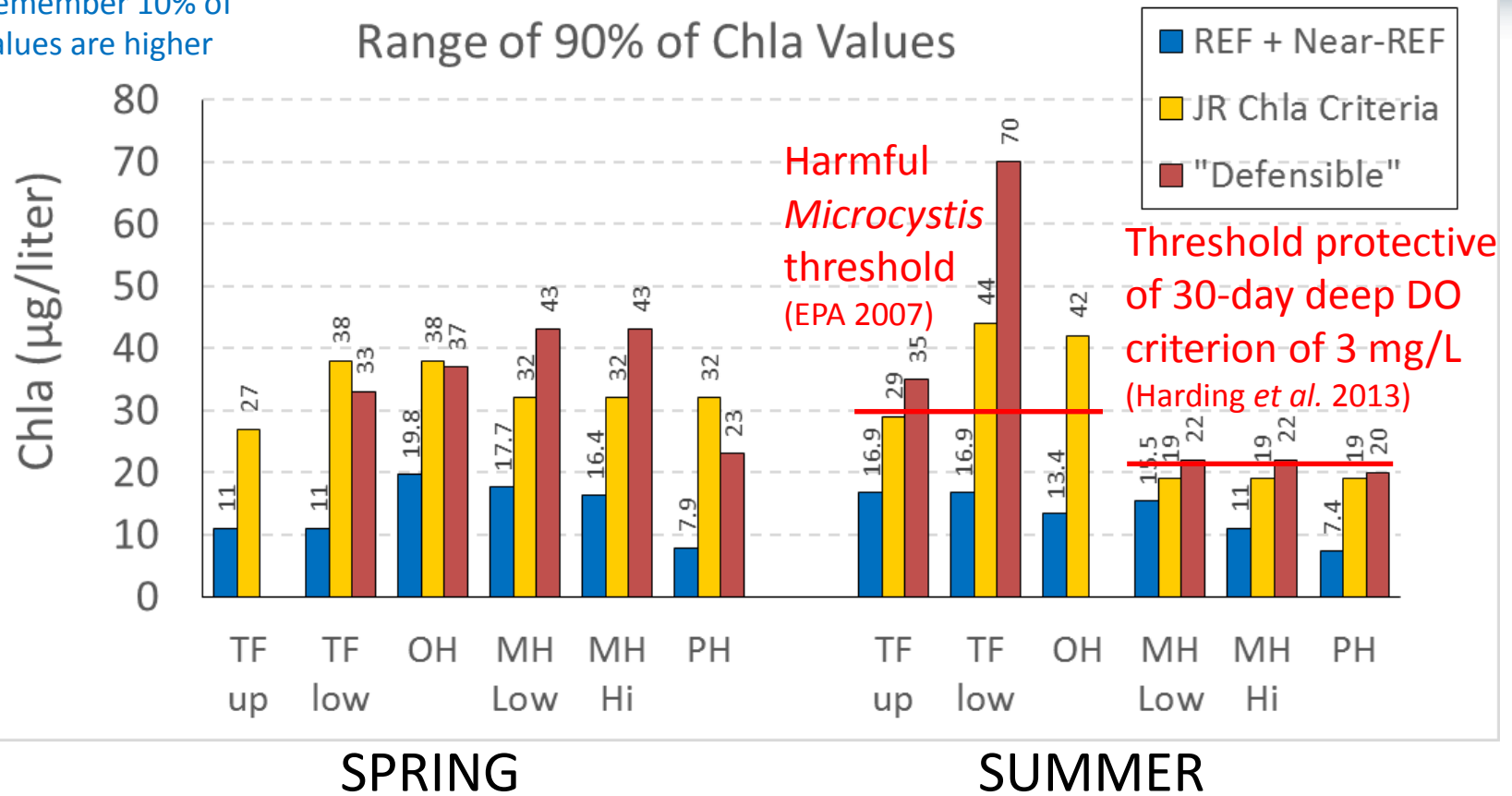
Regression analyses (e.g., EPA 2007, Harding *et al.* 2013); model results?

∴ Current criteria do not protect “balanced, indigenous, desirable” aquatic life

VII. Protectiveness of Chla Criteria (cont.)

Remember 10% of values are higher

Range of 90% of Chla Values

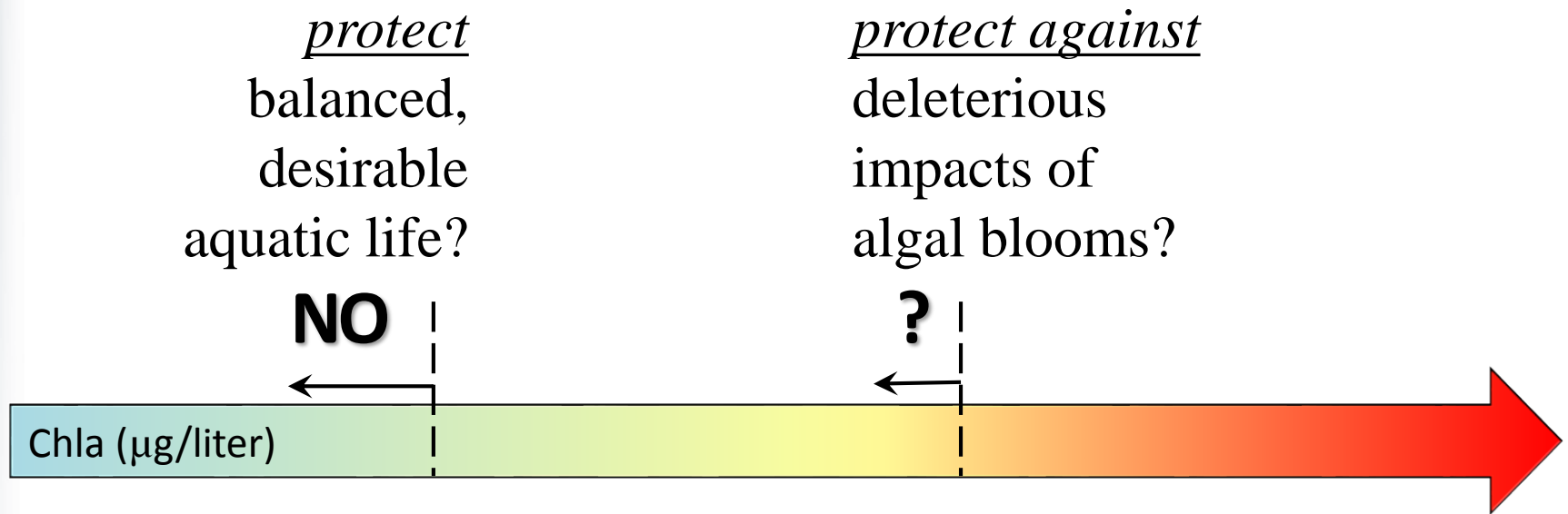


Note similarity in the ranges for most of the JR Chla Criteria and "Defensible"

See also Extra Slide 6

VII. Protectiveness of Chla Criteria (cont.)

Do the James River Chla criteria applied as the seasonal geometric mean...



The numeric values of the JR Chla criteria

- protect REF values only half the time as geometric means
- *would protect most of REF values if expressed as thresholds*

VIII. Choice of Chla Criteria Statistic

- Geometric mean or upper threshold?
- Keep or change the numeric values of current criteria?

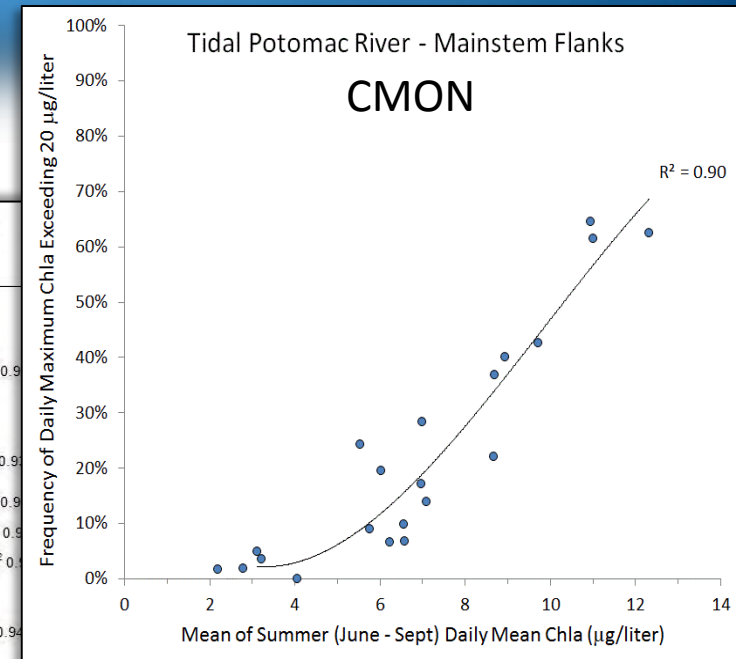
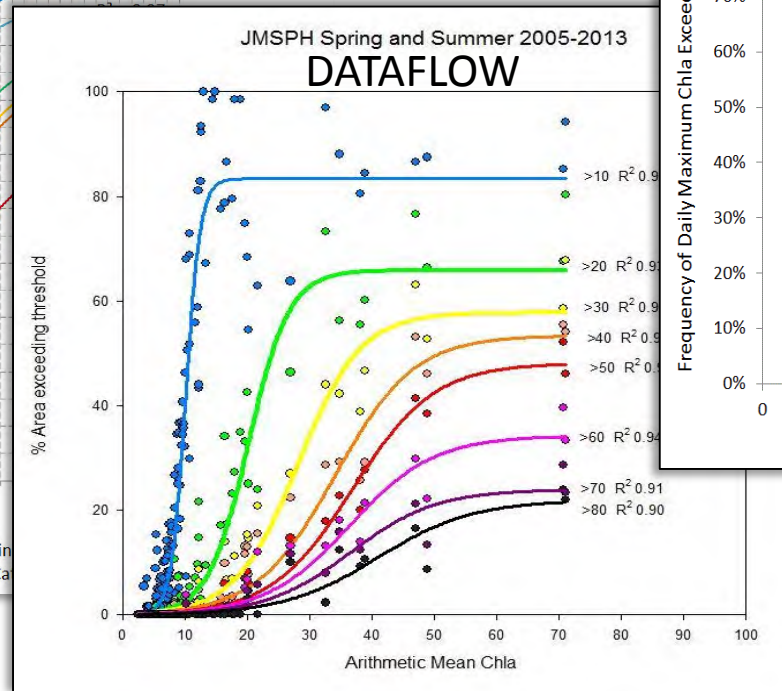
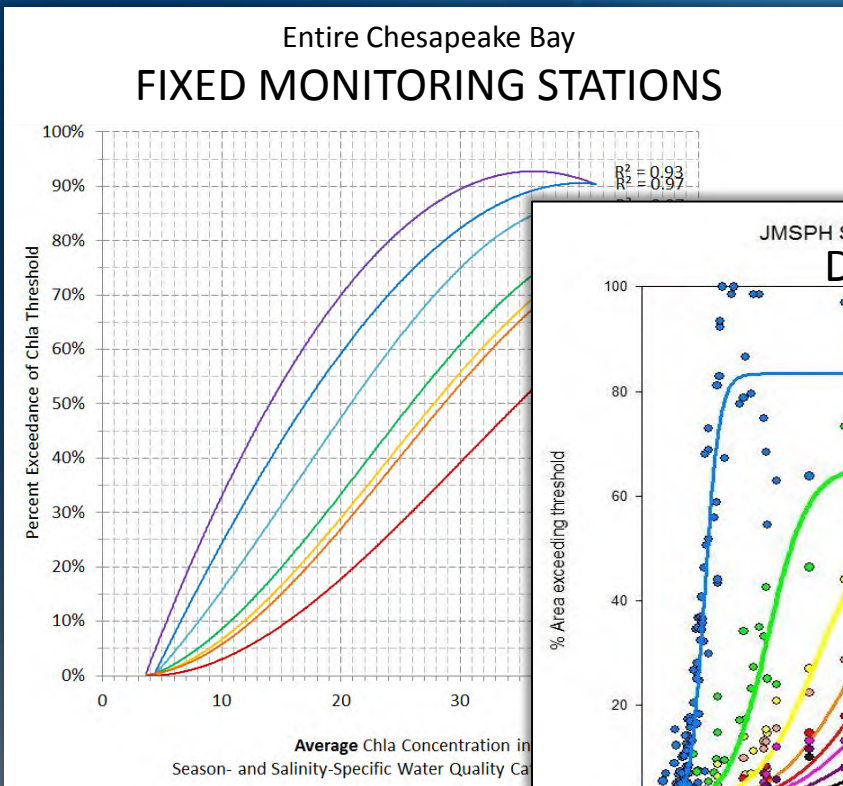
Points to consider:

Generally accepted that algal blooms (discrete high-Chla events) are ultimately responsible many deleterious effects

We know monthly, fixed station monitoring data are too sparse to accurately represent the frequency and extent of bloom events over short assessment periods

We know the statistical properties of large Chla data sets can indicate good and bad biotic integrity ... and the expected frequency and extent of blooms

VIII. Choice of Chla Criteria Statistic (cont.)



We can infer the frequency of threshold exceedances from means because of strong relationships between the mean and its upper limits

VIII. Choice of Chla Criteria Statistic (cont.)

Season	Salinity Zone	Benchmark “Good” median/mean (1)	Phyto. Reference median (2)	Phyto. Reference median/ mean (3)	Historical (1960s) geometric mean (4)	Central tendencies range	James R. chlorophyll <i>a</i> criteria
Spring	TF	3.1/3.5	4.3	3.0/4.3		3.0 – 4.3	10/15
Spring	OH	5.1/5.9	9.7	10.6/12.4	5.8	5.1 – 12.4	15
Spring	MH	6.9/7.2	5.6	5.6/7.8	2.6	2.6 – 7.8	12
Spring	PH	3.4/4.1	2.8	3.6/4.1	1.4	1.4 – 5.0	12
Summer	TF	7.3/6.9	8.6	6.3/8.6		6.3 – 8.6	15/23
Summer	OH	7.8/7.7	6.0	5.8/8.5	14.8	5.8 – 14.8	22
Summer	MH	8.4/7.9	7.3	7.6/8.1	7.3	7.3 – 8.4	10
Summer	PH	4.3/3.7	4.5	5.2/5.3	1.7	1.7 – 5.3	10

1. Olson (2002), 2. Buchanan et al. (2005), 3. from Buchanan (2014), 4. EPA (2007)

We know the central tendencies that protect desirable Ches. Bay phytoplankton ...these do not include the JR Chla criteria as geometric means ...

VIII. Choice of Chla Criteria Statistic (cont.)

Season	Salinity Zone	Benchmark “Good” 90th%ile (1)	Phyto. Reference 95th%ile (2)	Phyto. Reference 90 th /95 th %ile (3)	Historical (1960s) 1.2815 SD log-normal (4)	Upper limits range	James R. chlorophyll <i>a</i> criteria
Spring	TF	4.2	13.5	10.4/13.5		4.2 – 13.5	10/15
Spring	OH	9.8	24.6	22.6/28.7	18.2	9.8 – 28.7	15
Spring	MH	11.0	23.8	14.5/21.5	8.0	8.0 – 23.8	12
Spring	PH	12.9	6.4	6.8/7.3	4.3	4.3 – 12.9	12
Summer	TF	8.7	15.9	16.9/24.2		8.7 – 24.2	15/23
Summer	OH	10.8	24.4	17.2/23.2	45.7	10.8 – 45.7	22
Summer	MH	11.1	13.5	11.8/13.8	22.6	11.1 – 22.6	10
Summer	PH	6.0	9.2	7.4/8.0	5.1	5.1 – 9.2	10

1. Olson (2002), 2. Buchanan et al. (2005), 3. from Buchanan (2014), 4. EPA (2007)

... and we know their corresponding upper limits (thresholds) ...
which match the numeric values of the JR Chla criteria fairly well.

VIII. Choice of Chla Criteria Statistic (cont.)

One way forward:

Keep seasonal geometric mean as the Chla criteria statistic

Lower criteria's numeric values so the means correspond to Chla thresholds that will protect “balanced, indigenous, desirable” phytoplankton populations

Establish other goals or criteria that protect against undesirable or harmful algal blooms

Season	Salinity Zone	Ranges of [Chla] Central Tendency
Spring	TF	3.0 – 4.3
	OH	5.1 – 12.4
	MH	2.6 – 7.8
	PH	1.4 – 5.0
Summer	TF	6.3 – 8.6
	OH	5.8 – 14.8
	MH	7.3 – 8.4
	PH	1.7 – 5.3

(see also Extra Slide 7)

Looking Beyond Chla Criteria

Can Chla criteria alone always protect
“balanced, indigenous, desirable” aquatic life in
open waters?

NO

... because light has ultimate control over
growth of photosynthetic biota

Looking Beyond Chla Criteria (cont.)

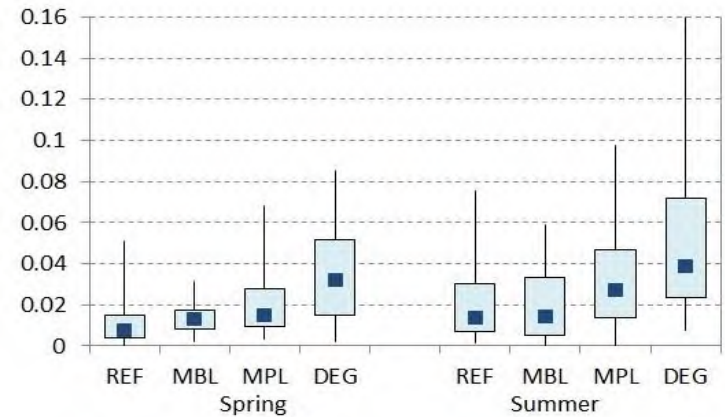
Phytoplankton cells are light-limited in Degraded waters except when close to surface – photosynthesis is stressed – facultative & motile taxa are favored

Phytoplankton are released from light limitation when water clarity improves or depth becomes shallower

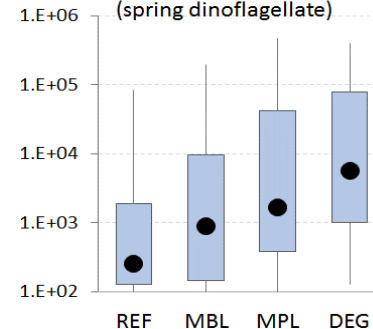
Nutrients then assert more control on growth

- Nutrient-rich → rapid growth (blooms)
- Nutrients almost limiting → slower growth

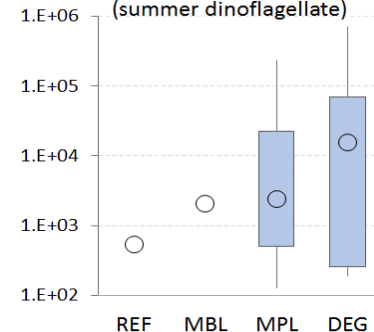
Chlorophyll Cell Content
(Chla:C)



Heterocapsa triquetra
(spring dinoflagellate)

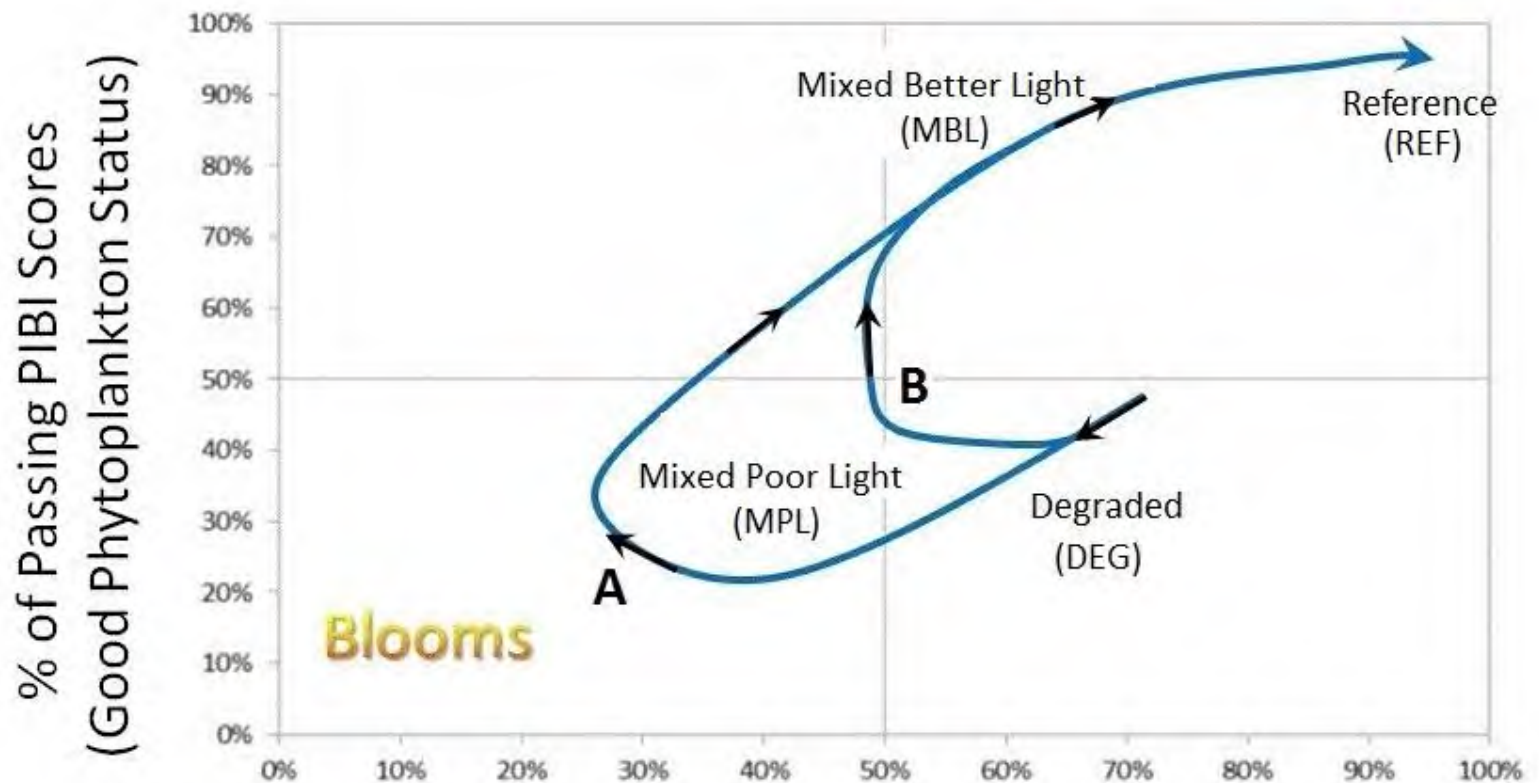


Cochlodinium
(summer dinoflagellate)



Looking Beyond Chla Criteria (cont.)

Conceptual diagram of possible recovery trajectory



% Meeting James River Chla Criteria Expressed as Upper Limits

A – very nutrient-rich

B – almost nutrient limited

Looking Beyond Chla Criteria (cont.)

Attaining Chla criteria and water clarity restoration goals in open waters can:

- address those cases where phytoplankton growth and Chla levels are suppressed by inadequate light
- fully protect phytoplankton Reference communities and by extension balanced, indigenous, desirable aquatic life in the open water designated uses

If SAV requirements for Secchi depth in nearshore waters were also applied to open waters, they would:

- meet phytoplankton requirements in TF & OH
- partially meet phytoplankton requirements in MH & PH [See also Extra Slide 8](#)

Using multiple criteria and thresholds to assess ecosystem health is sound science and is encouraged by EPA

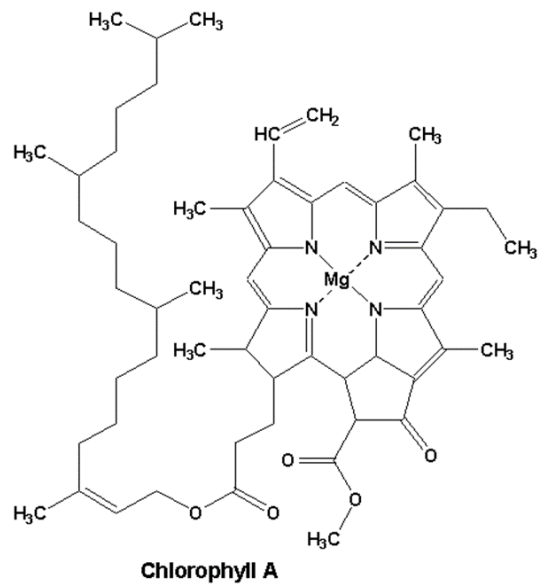
Summary

There is a logical progression of steps that directly links society's wishes (programmatic goals) to numeric Chla goals

Virginia's current Chla criteria, which are seasonal geometric means, *do not protect* the aquatic life designated use called for in state standards

The numeric values of the current criteria should be lower

Attaining both Chla criteria and water clarity restoration goals in open waters will *fully protect* aquatic life uses and *protect against* harmful algal blooms



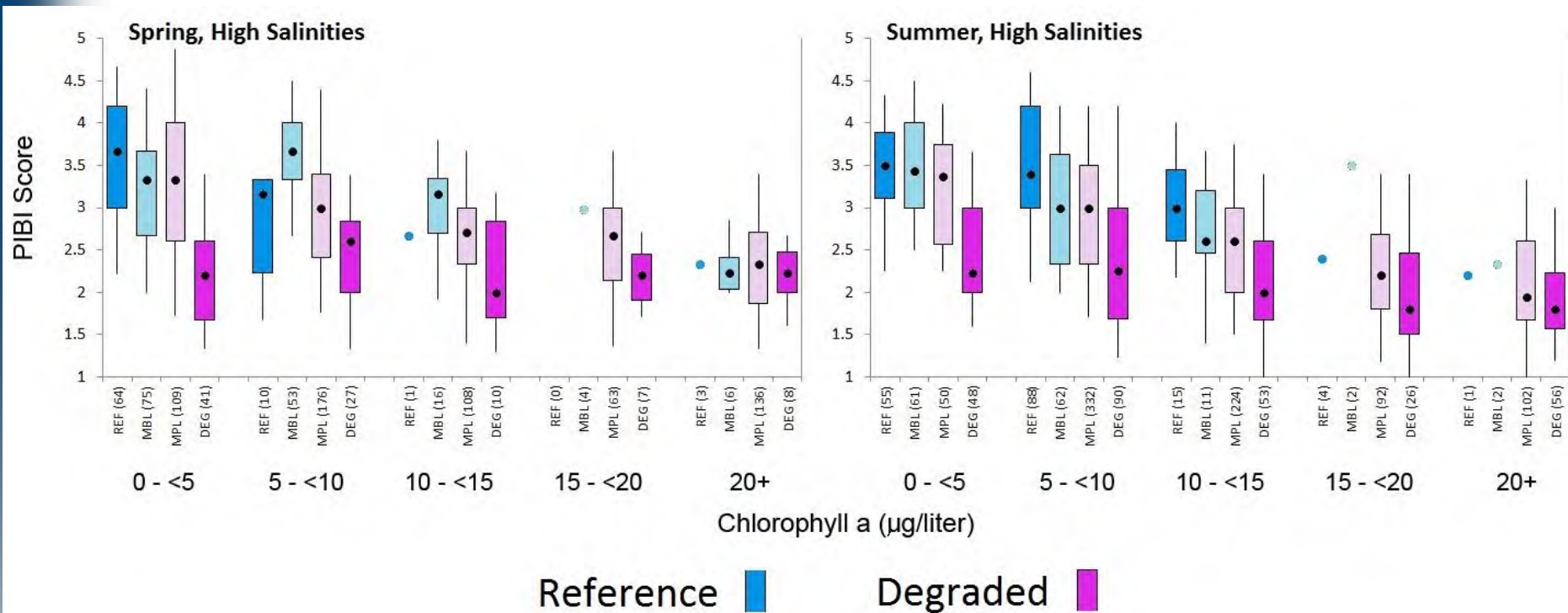
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Extra Slides

Extra Slide 1

Different communities in the same Chla increment illustrate water quality's influence

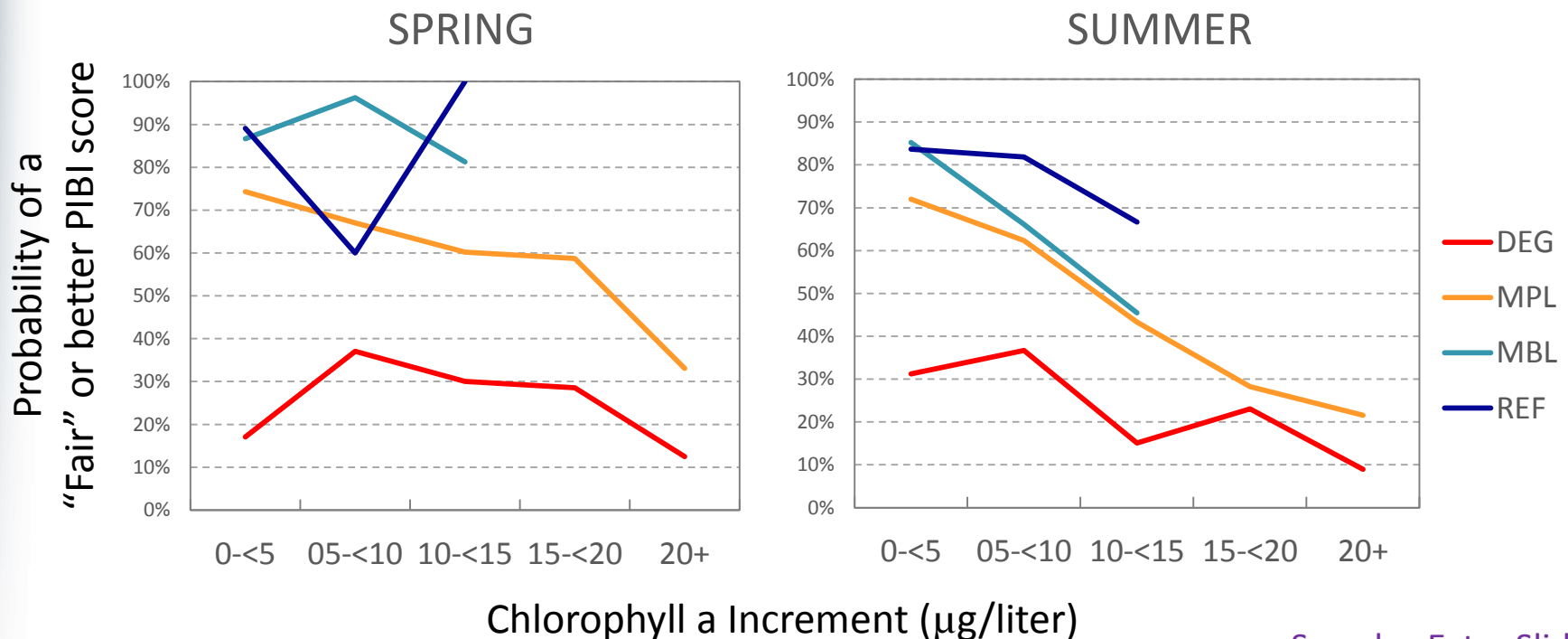


Extra Slide 2

Water quality's influence on conditional probability

The probability of high PIBI scores **changes** when Chla “condition” is also differentiated by water quality category

E.g., High Mesohaline + Polyhaline



See also Extra Slide 7

Extra Slide 3 Comparison of upper limits

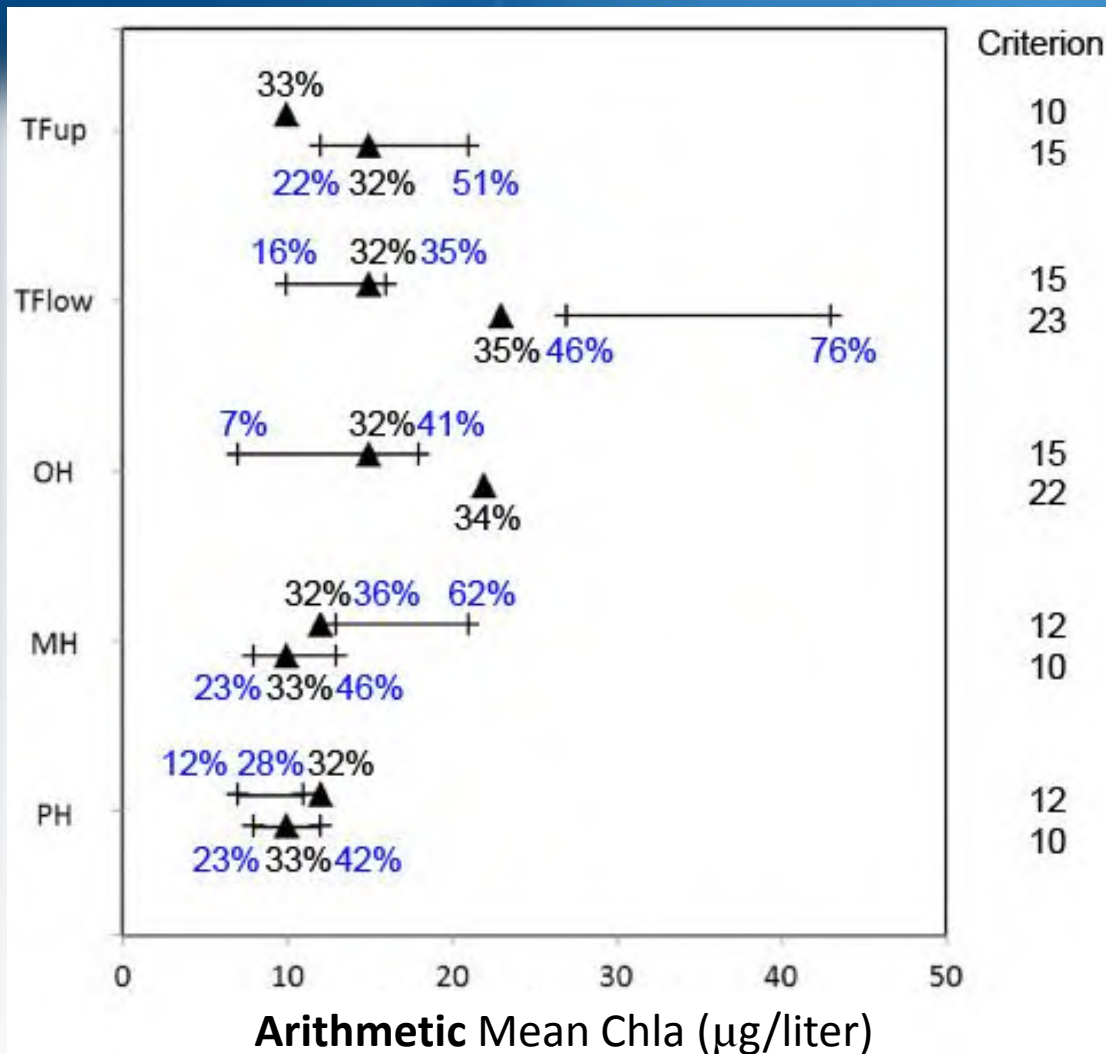
Approximate upper limits (90 th %ile) of Chla distributions for		
Salinity zone	current JR Chla criteria (seasonal geometric mean)	in Reference & Reference-like communities
<i>Spring (March – May)</i>		
TF (upper segment)	27	11.0
TF (lower segment)	38	
OH	38	19.8
MH	32	17.7 (low MH) 16.4 (high MH)
PH	32	7.9
<i>Summer (July – September)</i>		
TF (upper segment)	29	16.9
TF (lower segment)	44	
OH	42	13.4
MH	19	15.5 (low MH) 11.0 (high MH)
PH	19	7.4

Extra Slide 4 Percent exceedances of REF upper limits

Salinity zone	Threshold = Reference community 90 th %ile *	Percent of samples exceeding threshold when meeting current JR Chla criteria
<i>Spring (March – May)</i>		
TF	<11.0	42% (upper segment) 64% (low segment)
OH	<19.8	32%
MH	<17.7 (low MH)	25%
	<16.4 (high MH)	31%
PH	<7.9	64%
<i>Summer (July – September)</i>		
TF	<16.9	37% (upper segment) 68% (lower segment)
OH	<13.4	80%
MH	<15.5 (low MH)	23%
	<11.0 (high MH)	42%
PH	<7.4	60%

* From data used in Buchanan (2014)

Extra Slide 5 Percent exceedance of James River criteria expressed as upper limits



Numeric values of James River Chla criteria are used as thresholds. **Note:** the criteria numeric values are close to 90th percentiles of Reference popns.

%, percent of samples at the indicated *arithmetic* mean Chla that can be expected to exceed the numeric values of the current James River Chla criteria (on right).

▲, Chla criteria

+-----+, proposed defensible ranges

Extra Slide 6 Upper limits associated with “defensible ranges”

Salinity zone		~90 th %ile for the mean at the upper end of each defensible range	Note: 10% of Chla are <i>higher</i> than these values
Spring	TF (upper segment)	ND	
	TF (lower segment)	33	
	OH	37	
	MH	43	
	PH	23	
Summer	TF (upper segment)	35	
	TF (lower segment)	70	
	OH	ND	
	MH	22	
	PH	20	

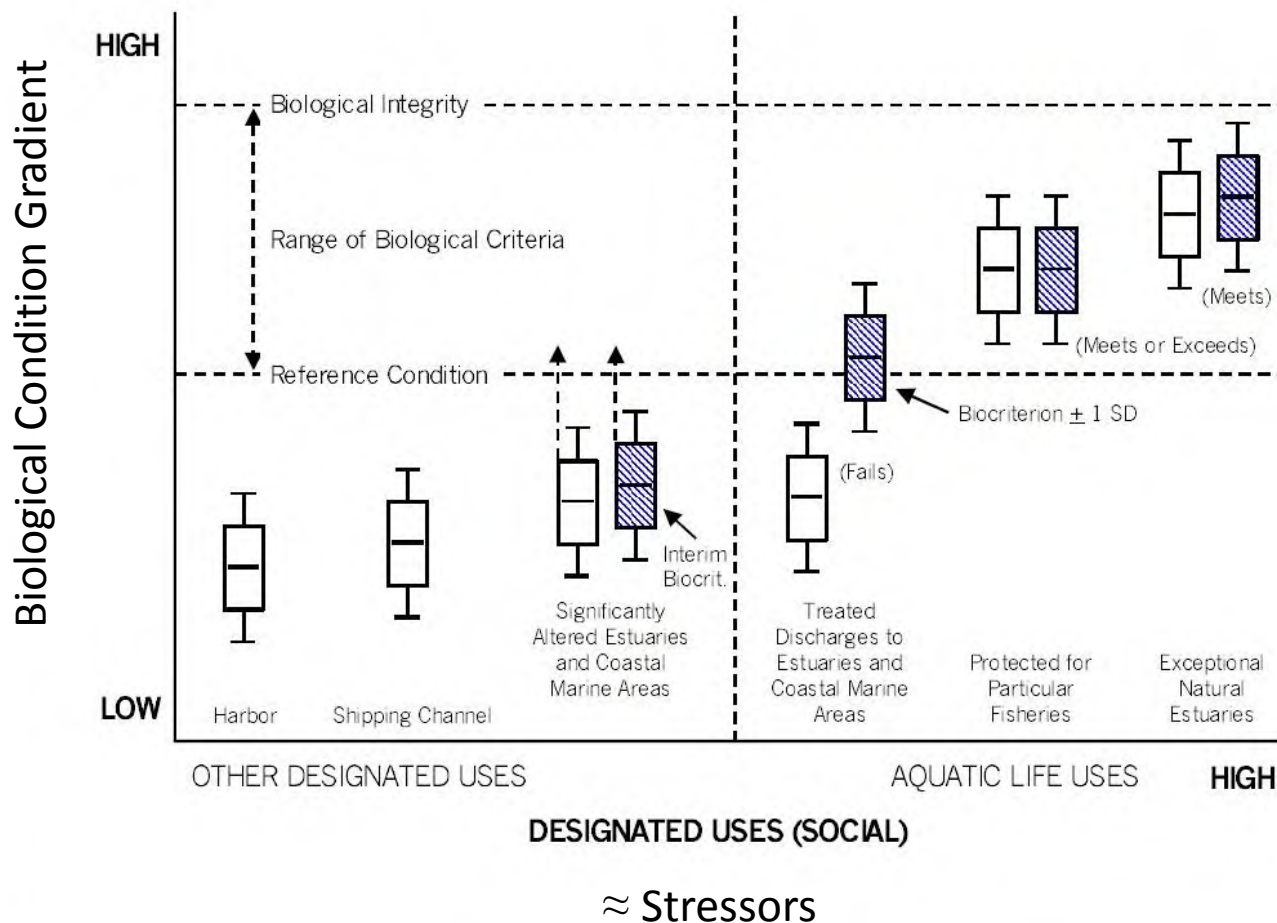
Extra Slide 7

Interim criteria can be useful to use in tracking restoration progress

Figure 1-1

Biocriteria for given classifications of estuaries and coastal marine areas. Shaded boxes represent the appropriate biocriterion range for selected classes. Unshaded boxes represent the range of measurement results for test sites in given classes. The vertical arrows above the boxes for the “significantly altered estuaries and coastal marine areas” class indicate the goal of raising the biocriterion for these waters over time in response to restoration efforts.

Gibson *et al.* (2000) Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance. USEPA.



Extra Slide 8

Water clarity thresholds for SAV and phytoplankton

Table 1. Thresholds of adequate water clarity for phytoplankton in open water habitats and for submerged aquatic vegetation (SAV) in nearshore habitats, expressed as Secchi depth, in meters. Sources: * Buchanan *et al.* (2005) for phytoplankton Reference communities; ** Buchanan (2015) for phytoplankton Reference communities, *** Batiuk *et al.* (1992) from SAV Technical Synthesis I (Secchi depth = 1.45/kd); *** Batiuk *et al.* (2000) from SAV Technical Synthesis II (Secchi depth = 1.45/kd).

Season/ Salinity Zone		Phytoplankton Thresholds *	Phytoplankton Thresholds**	SAV Restoration to 1 Meter ***	PLW Secondary Requirement ****
Spring	TF	>0.9	>0.8	>0.725	>0.711 (PLW=13%)
	OH	>0.7	>0.8	>0.725	>0.711 (PLW=13%)
	MH	>1.8	>1.4 (LoMH) >1.8 (HiMH)	>0.967	>0.958 (PLW=22%)
	PH	>2.15	>2.1	>0.967	>0.958 (PLW=22%)
Summer	TF	>0.8	>0.8	>0.725	>0.711 (PLW=13%)
	OH	>0.6	>0.8	>0.725	>0.711 (PLW=13%)
	MH	>1.45	>1.2 (LoMH) >1.6 (HiMH)	>0.967	>0.958 (PLW=22%)
	PH	>1.85	>1.8	>0.967	>0.958 (PLW=22%)

NOTES:

Slide	Notes
1	<p>SAP asked to “Provide final comments for revisions or adjustments to the existing chlorophyll related Water Quality Criteria.” (Paylor March 9, 2011 letter)</p> <p>Feedback from SAP members now would assist the agency in reviewing and interpreting the JR Chla Criteria Study results.</p> <p>VADEQ needs to decide soon if its current Chla criteria protect Virginia WQ standards.</p>
2	<p>This presentation summarizes my feedback to VADEQ - spelled out in white paper (dated 8/16/2015, circulated 9/16/2015). Tried to stay out of “the weeds” in this presentation. Details are in white paper.</p> <p>I see a logical progression of 8 steps that directly links society’s wishes (programmatic goals) to numeric Chla criteria <i>protective of</i> Virginia’s water quality standards.</p>
3	<p>1987 – “...entire natural system must be healthy and productive...” “...will determine the essential elements of habitat and environmental quality necessary to support living resources and will see that these conditions are attained and maintained.”</p> <p>1992 – “Achieve the water quality requirements necessary to restore living resources in both the mainstem and the tributaries.”</p> <p>2000 – “...recognize the interconnectedness of the Bay’s living resources and the importance of protecting the entire natural system.” “Preserve, protect and restore those habitats and natural areas that are vital to the survival and diversity of the living resources of the Bay and its rivers.”</p> <ul style="list-style-type: none"> • Commit to “specific levels of water clarity” (for SAV) by 2002; “continue efforts to improve water clarity in order to meet light requirements necessary to support SAV.” • “Define the water quality conditions necessary to protect aquatic living resources and then assign load reductions for nitrogen and phosphorus [to achieve conditions]...” <p>2014 – “Reduce pollutants to achieve the water quality necessary to support the aquatic living resources of the Bay and its tributaries and protect human health.”</p>
4	<p>Numeric thresholds used to create distinct water quality categories are presented in November 2013 presentation.</p>
5	<p>REF – light is adequate, N & P low enough to limit bloom formation</p> <p>MBL – light is adequate, no limits on N or P</p> <p>MPL – light is inadequate, no limits on N or P</p> <p>DEG – light is inadequate, N & P are both above bloom-limiting thresholds</p> <p>Liebig’s “law of the minimum” (mid-1800s)</p> <ul style="list-style-type: none"> - to identify nutrient deficiencies in agricultural soils - plant growth is controlled not by the total amount of resources available, but by the scarcest resource (limiting factor).

9	<p>Interesting recent result: exposure to UV-B can inhibit algal toxin production. UV-B (280–315nm) penetrates clear water. UV-B is quickly absorbed by particulates & DOM (especially CDOM) in turbid waters.</p> <p>Research suggests:</p> <ul style="list-style-type: none"> • Clear waters (REF) = High UV-B - <i>Microcystis</i> growth & toxin production <i>inhibited</i> • Turbid waters (DEG) = Low UV-B - <i>Microcystis</i> growth & toxin production <i>not inhibited</i> <p>Reference: Yang & Kong 2015 <i>Toxins</i> 7, 4238-4252 “Exposure to UV-B at intensities of 1.02 and 1.45 W/m² not only inhibited the growth of <i>Microcystis</i>, but also led to a decrease in the microcystin concentration.”</p>
12	Up to this point, we have been talking about phytoplankton <u>communities</u> – not chlorophyll <i>a</i> .
13	Large sample sizes needed to characterize frequency of algal blooms with any certainty
15	We instinctively know what a harmful bloom is – its just hard to quantify
16	<p>If Chla criteria is protective of (a desired condition), most Chla values will be below the criteria</p> <p>If Chla criteria is protective against (a harmful effect), most Chla values associated with that effect will be above the criteria</p>
17	<p>Can pick a central tendency value (mean, geometric mean, median) and determine the upper percentiles assoc. with that value.</p> <p>Not new news: Walker, W. W. (1985) Statistical Bases for Mean Chlorophyll <i>a</i> Criteria. Lake and Reservoir Management: Proceedings of Fourth Annual Conference. North American Lake Management Society, pp. 57-62.</p>
21	<p>Seasonal geometric means attaining the James R criteria:</p> <ul style="list-style-type: none"> - have distributions with 90th %iles up to 1.2x – 4.1x higher than REF 90th %iles - allow % exceedances of the REF 90th %ile of up to 23% - 80%
23	Ran upper ends of defensible ranges through the (arithmetic) mean-vs-90 th ile graphs - compared their upper limits to those of REF and of current JR Chla criteria
24	<p>Chla>30 µg/liter is associated with potentially harmful <i>Microcystis</i> abundances (EPA2007) in summer tidal fresh.</p> <p>Mainstem summer - no observations of bottom DO>3 mg/liter at mean May–Aug Chla>16 mg/m³; no bottom DO>2.0 mg/liter at mean May–Aug Chla>21 mg m³.</p>
25	<p>Irony</p> <p>When JR Chla criteria are expressed as seasonal geometric means, they only protect REF values roughly half the time (23% - 80%).</p> <p>If they were expressed as upper limits or thresholds, they would in fact protect roughly 90% of REF values since they approximate the values of REF (balanced, desirable aquatic life).</p>
28	Thru the statistical properties of large Chla data sets, we know Chla values that protect reference phytoplankton communities

	<p>Notice Chla central tendencies in different versions of Reference condition converge</p> <p>Notice how much higher the James R Chla criteria are.</p>
29	<p>Numeric values of James River Chla align closest to upper limits of reference popns</p> <p>Criteria's values more appropriately viewed as thresholds and not means</p> <p>Values from Harding <i>et al.</i> (2014) paper not included here, but the means and upper limits they show in their Figure 12 for Chla thresholds that they indicate are protective <i>against</i> toxic algal blooms, failing DO, and failing water clarity are close to or overlap the values shown here.</p>
30	<p>Including blooms that have water quality and food web effects, not just toxic impacts (Paylor March 2011 letter)</p> <p>"Other goals or criteria" could be for Chla.... First need to consider the following question.</p>
32	<p>In the mid-1980s, A. M. Wu-Seng Lung (professor of civil engineer at U. Virginia) modeled the tidal James River and determined that turbidity controlled phytoplankton growth in the estuary at that time. Light was the key limiting factor for phytoplankton; not nutrients.</p>
33	<p>% meeting James R Chla criteria in 5-year increments</p> <p>Criteria applied as upper limits is \approx REF popn. upper limits</p> <p>Poster at upcoming Coasts and Estuarine Research Federation meetings</p>
38	<p>For low Chla intervals (0-5, 5-10):</p> <p>1) high PIBI scores are much more frequent in Reference than in Degraded and fall off quickly as Chla increases.</p> <p>2) high PIBI scores Degraded are few and fall off gradually as Chla increases.</p>
44	<p>The Biological Condition Gradient (BCG) concept was whole-heartedly adopted and developed for streams and rivers by researchers and managers</p>
45	<p>Table 1 from "Programmatic Goals..." white paper.</p>